Thrust Bearing Retrofit:
A Case Study of the Cataract Generating Station

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ABSTRACT

Located on the Maine coast, the Cataract Generating Station, a single unit station owned by FPL Energy-Maine Hydro had experienced recurrent thrust bearing failures. The unit is a 9000 HP, Kaplan-type runner that started commercial operation in 1938. A review of maintenance history at Cataract has indicated the unit experienced eight thrust bearing failures since 1959, with four of them occurring since 2003.

Cataract had been taken out of service in August 2004 for a Kaplan oil leak and high thrust bearing temperature. Ultimately, the centerline of the unit had to be re-established because the station is experiencing the adverse effects of prolonged alkali-silica reaction. Following the extended outage, two commissioning attempts to re-start the unit after the overhaul were terminated due to thrust bearing failure. Cataract's original thrust bearing was a once commonly-used, two piece, flat plate design having a thrust runner plate with six radial grooves along the runner surface. This type of bearing had been widely installed in new machines, well into the 1940's. It is still commonly found today in generators of that vintage. Many hydro-station operators now seek to replace these thrust bearings with modern designs that are more robust and have higher load capacity. Retrofits, however, require careful evaluation and planning due to the low profile of the original design.

Hydro Tech Inc. of Sault Ste. Marie, ON, Canada, was contracted by FPL Energy in March, 2006 to design and supply a low profile eight-pad spring supported thrust bearing conversion including a new thrust block at Cataract. The advanced thrust bearing system incorporated individual PTFE-surfaced (PolyTetraFlourideEthylene) pads on a spring bed and a flat, one piece thrust runner plate with no grooves. Commissioned in early July 2006, this conversion was very successful and has resulted in lowering the running temperature of Cataract's thrust bearing by 33 deg C. The recorded August 2004 thrust bearing temperature of 83 deg C (prior to shutdown) has been reduced to 50 deg C. The oil bath temperature has also been substantially reduced by 25 deg C. In addition, the newly designed PTFE thrust bearing is expected to require less maintenance due to its durability and its higher load capacity. It is expected to also accommodate on-going misalignment from alkali-silica reaction more successfully than the original plate-type bearing.

Background

Cataract is a run-of-the-river station which is the last station on the Saco River and subject to tidal fluctuation. This station has a single unit and is the only power generating hydro facility in a complex of four dams in an urban setting. The unit is a

single Kaplan unit rated at 9,000 HP. The station began operation in 1939 and is presently owned by FPL Energy.

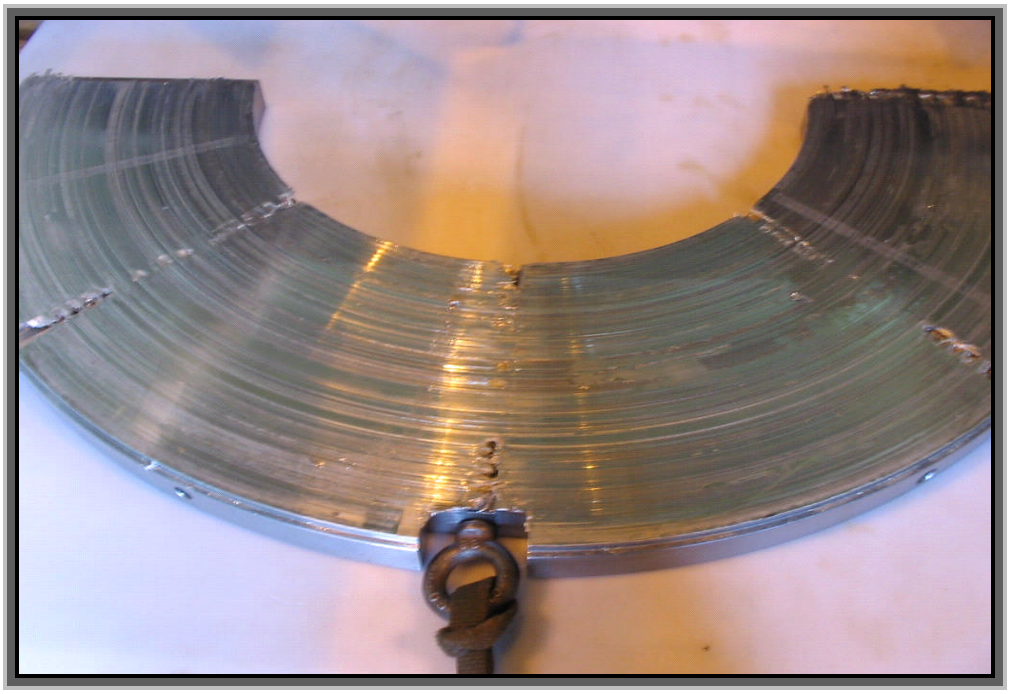
In 2004, the unit was taken out of service to address an oil leak in the Kaplan head. Upon disassembly, a number of conditions adverse to continued operation were discovered. The thrust bearing babbitt shoes were cracked and required corrective action. Additionally, misalignment at the station due to Alkali-Aggregate Reactivity (AAR) had progressed to such a degree that the centerline of the unit had to be reestablished. This work took approximately ten months to complete prior to completing reassembly and prepping the unit for startup.

The thrust bearing at Cataract is above the rotor and contained in the upper bridge which also houses the upper guide bearing. There is a lower guide bearing under the rotor and a LV style turbine bearing in the headcover. The thrust bearing at Cataract has not had a history of good service and has failed eight times since 1959. The history leading up to this resulted in a repair in 1959 that included sleeving the thrust block due to eccentric wear over the initial operating period.

First Startup Failure

Initial startup at the station took place in June, 2005 using normal startup procedures. Mechanical runs were conducted without incident. Subsequently, an auto-start sequence was initiated and shortly thereafter, the unit was tripped on high thrust bearing temperature. Subsequent inspection showed a severely wiped bearing with a babbitt-filled oil reservoir as seen in Figure 1.

Figure 1. Photograph of Failed Babbitt Plate from June, 2005



An investigation was conducted to determine the cause of failure. A conclusive root cause was not determined at this time. One item noted during the disassembly of the failed bearing showed that the round keys that hold the split thrust runner halves in place to each other were distressed. There are two keys held in place by set screws and one key was ejected and in the thrust bearing oil reservoir and one was still in place. Both had sheared set screws. A small amount of displacement was noted between the thrust runner halves.

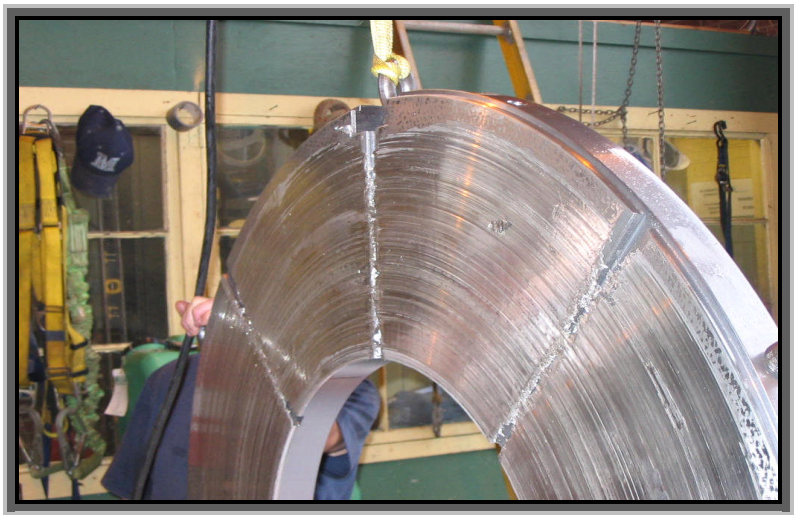
Recovery from this failure involved a series of steps that included thrust bearing component reengineering. A new, split half thrust runner was built that included a robust key set to address the disrupted runner issue from the June 2005 failure. Additionally, a two piece babbitt plate was provided to replace the existing damaged babbitt plate. This was because there was a concern with warping the original babbitt backing plate during the rebabbitting process. The unit was reassembled and subsequently prepared for restart in September, 2005.

Second Startup Failure

During the September, 2005 startup, a specific startup procedure and organization was developed to address potential issue from the June startup failure. This included a program of progressive starts and stops consisting of mechanical runs at various speeds, speed-no load runs, runs of varying duration to address heat-up and cool-down, as well as intermediate inspections and cleaning and scraping to ensure there was no potential failure mode operating.

The second startup progressed normally through a run that included flashing the field. Subsequent to that variable, the unit was auto-started and synchronized. Thrust bearing temperatures started to climb dramatically and the unit was tripped. Upon disassembly, a preferential wipe in the babbitt was discovered that was so severe the unit had to be disassembled and thrust bearing components either had to be repaired or replaced (Figure 2).

Figure 2. Photograph of Failed Babbitt Plate from September, 2005

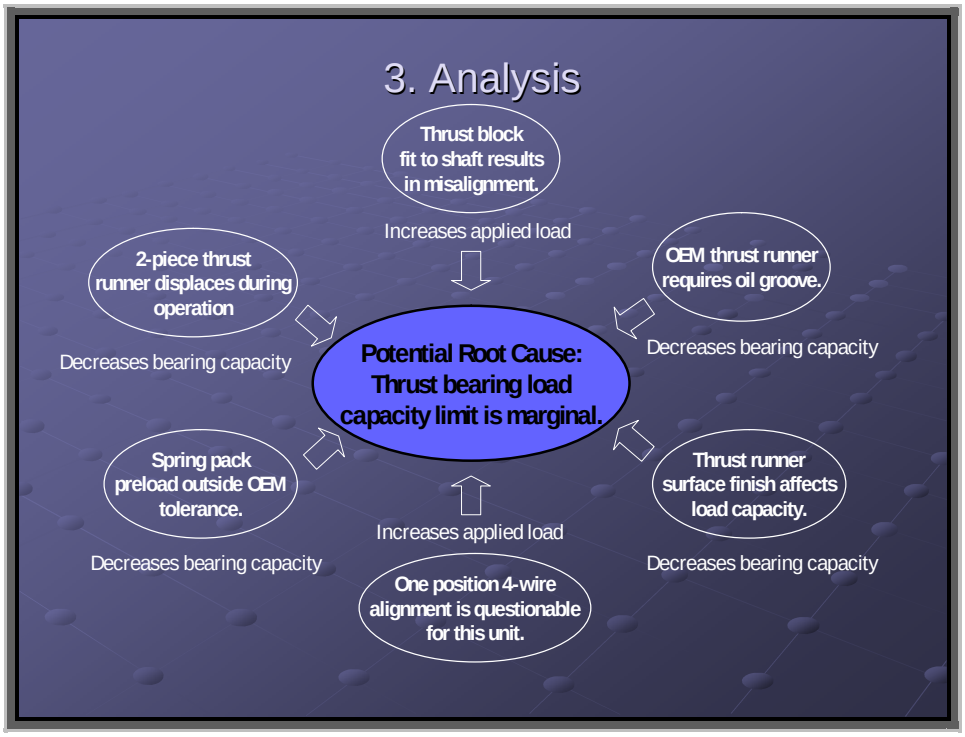


Post Failure Recovery Activities

Upon disassembly after the second failure, displacement was once again noted between the two halves of the thrust runner, despite the enhancements made to the keys to improve their rigidity and stiffness. At this time, the thrust bearing was completely removed from the unit and a multidisciplinary team was assembled to determine root cause for thrust bearing failures and the appropriate corrective actions to prevent recurrence.

After an exhaustive study, evaluation of failed components, and consultation with a number of experts in the field of thrust bearing performance, the review team came up with a list of one potential root cause and six contributors that enhanced the likelihood of the root cause. The team determined the likely root cause of both failures was due to the marginal load capacity of the original bearing (the subject of the initial startup failure and the reengineered bearing (the subject of the second startup failure).

Figure 3. Root Cause and Contributors Diagram for Cataract Failures in 2005


3. Analysis
Thrust block fit to shaft results in misalignment.
Increases applied load
2-piece thrust runner displaces during operation
Decreases bearing capacity
OEM thrust runner requires oil groove.
Decreases bearing capacity
Potential Root Cause: Thrust bearing load capacity limit is marginal.
Spring pack preload outside OEM tolerance.
Decreases bearing capacity
Thrust runner surface finish affects load capacity.
Decreases bearing capacity
Increases applied load
One position 4-wire alignment is questionable for this unit.

It has been widely reported that two piece babbitt bearings on spring beds in hydro service have lower load-bearing capacity than more modern independent pad bearings (Ref. 1, 2, for example). In the case of the thrust bearing at Cataract, calculations indicate that the design load is within 10% of the limit for babbitt, which is reported to be 400 psi (Ref. 3). With such a small margin and other factors at the station, including most notably, a situation with AAR that will progressively increase the amount of misalignment at the station, the focus moved away from refurbishing the existing two piece spring-bed bearing to retrofitting a higher capacity bearing.

Flat Plate Thrust Bearing

The thrust bearing assembly consists of two flat annular rings, one fixed to the shaft, one to the housing. These rings turn against each other in a flat-bottomed “pot” which holds a bath of non-compressive hydraulic oil. The bottom ring (the “bearing plate”) is fixed to the pot bottom, and usually has six or eight radial grooves to promote continuous feed of oil between the surfaces of the two plates; the stationary bearing plate has a babbitted bearing surface (Figure 4). The top rotating ring (the “runner” plate) turns with the shaft. As is typical with this style of bearing, the runner plates also have radial grooves.

Figure 4. Babbitted Bearing Plate - Flat, Spring Supported Style

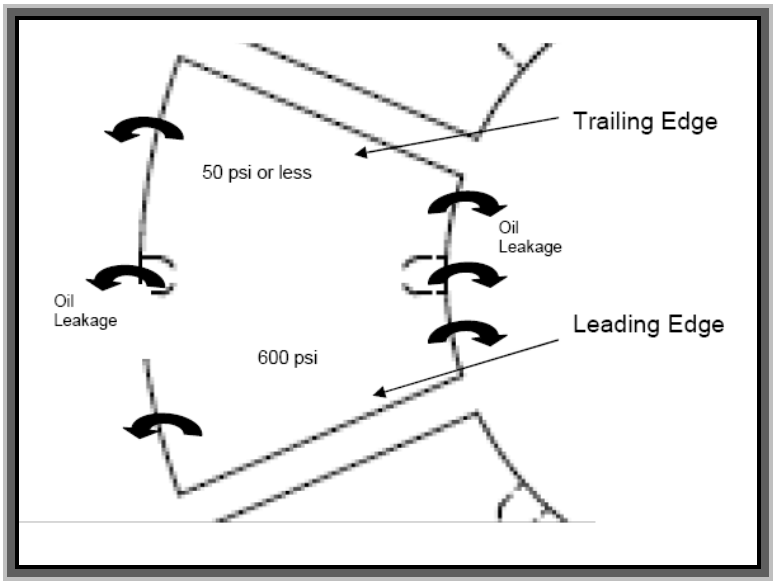
The typical flat plate thrust bearing was a marine design used for many years on ships. The original design of the flat plate thrust bearing came as either one complete base ring, or in two base ring halves. Both arrangements had babbitted bearing pad sections bonded to the base plate. This arrangement was frequently held by blocks in four places on the outside diameter of the bearing base plate(s). The thrust runner plate for this bearing was a micro finish plate with radial grooves on the running surface. These grooves acted as a centrifugal oil circulating pump for the bearing pot. This design was largely used in many generators as late as the mid 1940’s.

After this time, it was common knowledge among bearing designers that a tilting pad plain bearing had a 2 to 4 times greater load carrying capacity than the flat plate design. A flat plate babbitt bearing design can safely operate at approximately 150 psi compared with the 400 to 450 psi of a babbitt tilting pad design. The PTFE tilting pad bearing has a design load of 6.5 MPa (943 psi), which is more than twice that of babbitt. All three styles of bearings have operated successfully at greater than the design loads, however, the design safety factor is reduced.

Babbitted Bearing Plate Design Limitations

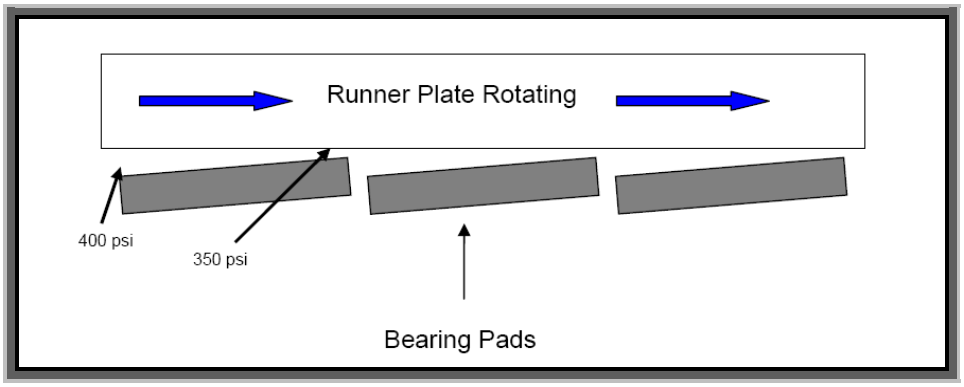
Flat plate babbitt pads are bonded to a single base plate, keeping them parallel to the runner (rotating) plate. Lubrication is drawn onto a bearing pad's surface by oil sticking to the runner plate as it rotates; this creates an "oil wedge" at the leading edge of the bearing pad. As oil travels along a pad, some oil leaks from the inner and outer pad edges, thereby, leaving less oil pressure at the trailing edge of the bearing segment (Figure 5). This is an effect of the bearing pad's parallel position to the running surface, resulting in reduced oil pressure at the back of the pad due to oil leakage. This leaves only the leading edge of the pad to support the majority of the thrust load. The effective working area of the flat plate bearing pad is only about 1/3 its surface area.

Figure 5. Flat Plate Design for Oil Wedge



By contrast, a modern bearing design uses a forward-tilting pad to create a smaller gap between the runner plate and back of the bearing pad. This allows the trailing edge of the bearing pad to maintain pressure despite reduced oil (Figure 6). Thus, a more even distribution of load is created along the entire bearing surface, and the thrust carrying capacity is increased.

Figure 6. Tilting Pad Design Oil Wedge



Thrust Runner Plate Design Limitations

The thrust runner plate resembles a runner plate of current design, except for the presence of radial grooves on the face of the running surface as shown in Figure 7. Originally designed to circulate oil in the bearing pot, and to wash cool oil over the face of the babbitt pads, these radial grooves actually contribute to the bearing's downfall. As the grooves pass over stationary pads, the oil wedge is broken, thus allowing pressure developed to support the thrust load, to drain from the radial groove. This results in an unequal distribution of load on the thrust bearing pads by changing pressure across the bearing pads from maximum to zero pressure (six or more times per revolution depending on the number of radial grooves).

Figure 7. Grooved Thrust Runner Plate

Such extreme pressure changes inevitably cause problems. "Oil pressure hammer" may cause fatigue cracking of the babbitted surface. Additional cases have been documented where pressure drop on a babbitt bearing pad has resulted in cavitation. In both cases, the higher the bearing is loaded, the more rapidly its failure will occur. These failures are sometimes difficult to detect due to the very nature of their occurrence. The bearing operates perfectly while slowly deteriorating; then, after several years of operation, the bearing suddenly self-destructs, leaving little evidence as to the root cause.

Upgrading the Flat Plate Bearing

Conversion of the flat plate bearing to a tilting pad arrangement presents obstacles that are inherently difficult to overcome:

- Finding a way to hold the individual pads in place
- Frequently, the thrust pad arrangement is very low profile, making it difficult to fit a tilting bearing in the height available

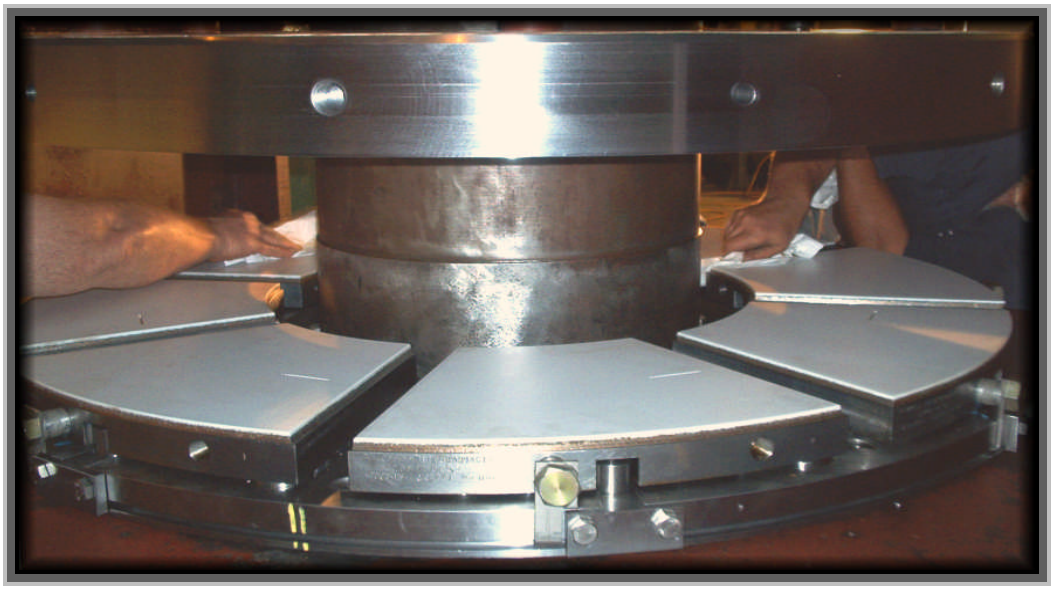
- Maintaining the ability to easily adjust the bearing pads for alignment and even pad load distribution

To have six, eight, or more tilting shoes replace the old bearing, one must have a design which can withstand torque developed by the generator on the bearing. Each pad must be held individually to the bottom of the thrust pot.

In many cases, the original design will have a very low profile. With Cataract, the combined support system and bearing pad height was confined to 4 1/16 inches. Having such a low profile made it difficult for any individually adjustable shoe arrangement. To allow individual shoe adjustment, the bearing pot would likely have to be modified.

This obstacle was overcome by designing a new way in which to support the bearing and hold the bearing pads without modifying the bearing pot (Figure 8). Once the four blocks for the old bearing were removed, the new support system was installed, in a single morning, by two tradesmen. The new, rigged, support system supplies a greater thrust load capacity than the previous bearing, and because of the greater efficiency of the PTFE bearing (5 times lower coefficient of friction), results in reduced torque load.

Figure 8. Converted PTFE Thrust Bearing



The new Cataract bearing now operates at 50 degrees Celsius (about 30 degrees lower than the previous operating temperature). The oil bath temperature was significantly reduced by 25 degrees Celsius. This is especially important during operation in the summer months where the Unit has a history of running hot due to high ambient temperature and increased river temperatures (cooling water to the thrust bearing oil reservoir.

Conclusion:

At Cataract station, a number of factors caused bearing failures over the last 50 years, and particularly during the startups from a major overhaul. This included a bearing design capacity that was marginal for the conditions, increased loads on the bearing due to misalignments caused by concrete growth associated with AAR, and decreased bearing capacity due to modifications implemented to a bearing design that is not fully understood.

The station was retrofitted with an PTFE design using individual pads and springs in the existing bearing envelop. The goal behind this retrofit was to install a bearing design that could tolerate a wide variety of operating and induced loading without significantly impacting bearing design margin capacity. This was successfully achieved as evidenced by a successful startup and subsequent operating history. Both bearing operating temperatures and oil bath temperatures by were reduced by approximately 30 and 25 degrees Celsius, respectively.

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